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MINERALS AND ELEMENTS: USING PETROGRAPHY TO RECONSIDER THE FINDINGS OF NEUTRON ACTIVATION IN THE COMPOSITIONAL ANALYSIS OF CERAMICS FROM PINSON MOUNDS, TENNESSEE

James B. Stoltman and Robert C. Mainfort Jr.

ABSTRACT

Of 164 sherds and soil samples from Pinson Mounds and vicinity previously analyzed by neutron activation analysis (NAA), 39 specimens (plus 13 other "local" sherds) were subjected to petrographic analysis. The goal of this study is to assess the differential effectiveness of the two techniques to discriminate locally produced from imported ceramic vessels at prehistoric sites. The conclusion of the NAA that "none of the analyzed sherds with nonlocal surface treatments was manufactured from nonlocal clays" is contradicted in several cases, thus calling into question the effectiveness of NAA to address reliably issues of ceramic production and exchange.

Ceramic composition can provide archaeologists with valuable information about many aspects of human behavior, including resource procurement, technology, organization of production, and cultural interaction (including exchange). The compositions of archaeological ceramics are normally characterized either chemically or physically. Various techniques have been employed to determine the chemical composition of ceramics, but neutron activation analysis (NAA) is used most commonly. The leading technique for determining the physical composition of ceramics is petrography. The two approaches characterize ceramic compositions in distinctly different ways—the former in terms of *chemical elements*, the latter in terms of *minerals and rocks*—and are generally believed to provide complementary information. The present study provides an empirical test of that supposition by subjecting to petrographic analysis a series of sherds from Pinson Mounds and vicinity in western Tennessee whose compositions have previously been determined by NAA.

In several previous studies, neutron activation and petrography have been employed jointly in the analysis of archaeological ceramics (e.g., Rands and Bishop 1980; Strazicich 1998; Triadan 1997; Zedeno 1994). The present study differs, however, in that petrography is utilized as an independent test of the findings of NAA rather than serving primarily "in a supportive and interpretive role" to NAA (Rands and Bishop 1980:19). The petrographic analysis of a

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uniquely large number of samples previously analyzed by NAA—35 sherds and four soils—substantially contradicts the findings of the earlier analysis, thus raising serious concerns about the complementarity of the two approaches for addressing questions of production and exchange of prehistoric ceramics.

Pinson Mounds (40MD1) is located in the West Tennessee Uplands physiographic province in Madison County, Tennessee, a region underlain by unconsolidated sediments of Cretaceous and Tertiary ages (Floyd 1965:9, 15; Figure 1). The site includes at least 12 mounds, an earthen enclosure, and several specialized activity loci extending over an area of approximately 160 ha. Long considered a Mississippian site based on the presence of five large, flat-topped, rectangular mounds, it was not until the 1970s and 1980s that intensive excavations confirmed its Middle Woodland affiliations (e.g., Mainfort 1980, 1988, 1996;

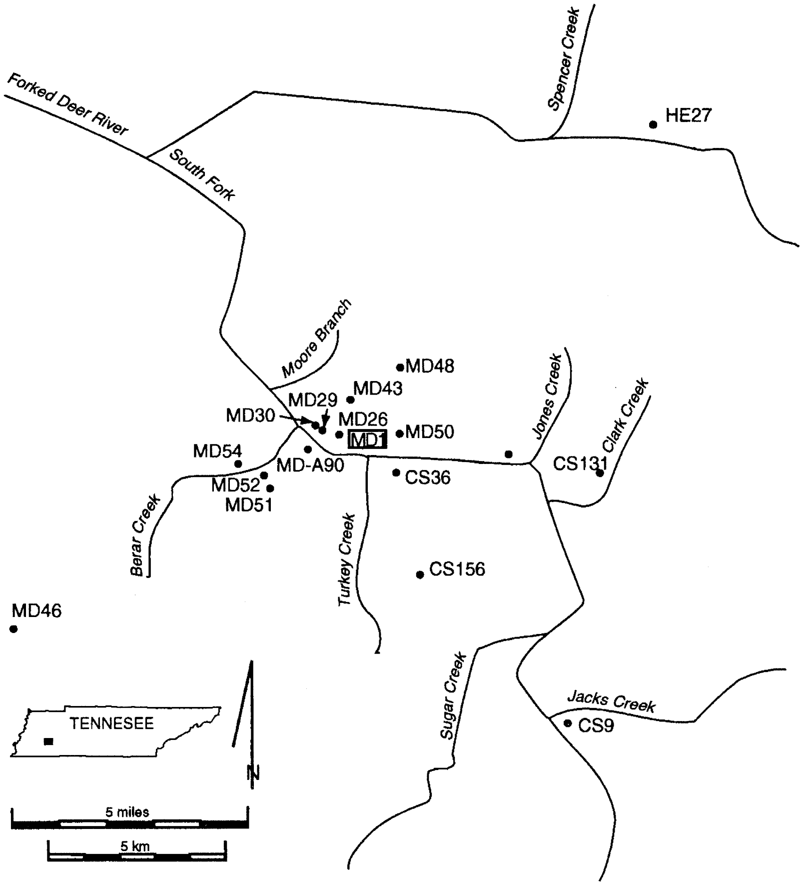

Figure 1. Location of Pinson Mounds and nearby sites providing ceramic/clay samples for this study.

Mainfort and Walling 1992). Pinson Mounds is now considered the largest Middle Woodland site in the Southeast (Bense 1994:154; Mainfort 1988:168, 1996:384).

The closest cultural affinities of Pinson are generally regarded to be with the Miller culture of northern Mississippi (cf. Jenkins 1979:172, 1982:82–83; McNutt 1996:215; Mainfort and Walling 1992). Like Miller culture ceramics, Pinson ceramics are sand tempered, consisting mainly of the types Furrs Cordmarked, Baldwin Plain, and Saltillo Fabric Impressed (e.g., Mainfort 1986; Mainfort and Chapman 1994; Mainfort and Walling 1992:122–123). Unlike "classic" Miller I-II assemblages, however, some grog- and mixed grog-and-sand-tempered ceramics occur at Pinson Mounds in Middle Woodland contexts (Mainfort and Walling 1992:122–123). In part, this probably reflects regional variation in ceramic technology. Some of the grog-tempered sherds probably represent vessels imported from the Mississippi Valley, and there are a number of other sherds that, on the basis of temper or stylistic properties, coupled with their discontinuous distribution and minority status at the site, have been regarded as trade vessels. Principal among these are vessels characterized by one or more of the following attributes: complicated stamping, check stamping, simple stamping, red filming, incising, burnishing, limestone temper, grit temper, and bone temper (Mainfort 1986:35–46, 1996:386; Mainfort and Walling 1992:121–124; Figure 2).

In 1997 the generally accepted view of the Pinson ceramic assemblage was dramatically challenged on the basis of neutron activation analyses of 164 sherd and clay samples from Pinson Mounds and 20 other sites located within a 20-km radius of the site (Mainfort et al. 1997). Six samples of Swift Creek Complicated Stamped pottery from three sites in Georgia were also analyzed. The Tennessee samples consisted of 117 sherds and three fired clay fragments from Pinson Mounds itself, 39 sherds from neighboring sites, and five clay samples from the region. While most specimens were presumed to be of local derivation, at least 19 of the Pinson Mounds sherds were suspected to be nonlocal products (i.e., from beyond the 20-km radius that delimits the present sample), based on the criteria mentioned above. The latter category included five complicated-stamped, six check-stamped, two simple-stamped, two limestone-tempered, two burnished, and two Marksville Stamped sherds (Mainfort et al. 1997:47). As a result of the neutron activation findings, it was concluded that "all samples submitted from Pinson Mounds and nearby sites are probably of local origin" (Mainfort et al. 1997:62). Moreover, with respect to the "large number of pottery sherds that exhibit nonlocal decorative attributes," it was further concluded that "neutron activation analysis has conclusively demonstrated that the sherds in question were produced locally" (Mainfort et al. 1997:65). These findings were aptly described as "unexpected" (Mainfort et al. 1997:65).

At the time the results of the NAA were published, the senior author was in the midst of a multiyear study of cultural interaction between the Hopewellian centers of southern Ohio and the southeastern United States based on the petrographic analysis of ceramics. Included in this analysis were 10 sherds from Pinson Mounds and three from nearby sites that had been provided by the junior author.

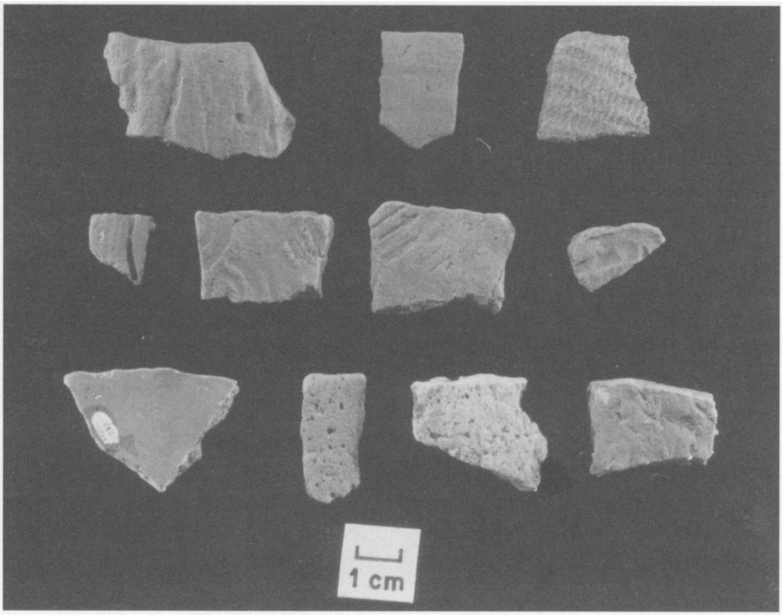

Figure 2. Selected Pinson Mounds sherds. Upper row: Furrs Cordmarked (40-90/PM-0089), Baldwin Plain (PM-0066), Saltillo Fabric Impressed (PM-0076); middle row: Marksville Stamped (40-68/PM-0084), Swift Creek Complicated Stamped (40-56/PM-0013), McLeod Simple Stamped (40-62/PM-0061), untyped check stamped (PM-0119); bottom row: Larto Red (40-66/PM-0068), plant (?) tempered plain (40-67/PM-0071), limestone-tempered cordmarked (40-65/PM-0067), grit-tempered cordmarked (40-61/PM-0060).

These 13 sherds had been selected with the primary goal of providing a local signature for the petrographic composition of Pinson ceramics. The Pinson Mounds materials seemed to provide an ideal opportunity to compare and contrast the findings of the two approaches as applied to a common data set, thereby furthering the interest in exploring and trying to make explicit the relative strengths and limitations of petrography and elemental analysis in determining ceramic compositions (an earlier such effort was inhibited by a small sample; see Stoltman et al. 1993). Conversations between the two authors revealed that none of the 13 thin-sectioned sherds had been included in the NAA, so direct comparison of the findings was not possible. Remnants of many of the sherds that had been included in the NAA study were still extant, however, and 39 of those sherds were thin sectioned. The current study, then, is based on the thin-section analysis of 52 sherd and clay samples from Pinson Mounds and vicinity, 39 of which were included in the NAA study. This article critically evaluates the differential results of the two approaches and considers their implications in assessing the relative merits of the approaches in answering questions related to issues of ceramic production and exchange. In the ensuing discussion, we first present the findings of the petrographic analysis and then consider their implications for the NAA.

Petrographic Findings

The 52 samples subjected to petrographic analysis for this study consist of 32 sherds from Pinson Mounds, 16 sherds from 13 nearby sites, two fired-clay samples from Pinson Mounds, and two clay samples associated with nearby historic stoneware potteries (Figure 1). The thin sections for these specimens were analyzed using a basic point-counting procedure as outlined by Stoltman (1989, 1991). As a result of this analysis, the percentages of silt-size inclusions plus the species, sizes, and percentages of mineral inclusions of sand size and larger were ascertained and used to characterize the physical composition of each thin section. During this stage, precautions were taken to ensure that each thin section was analyzed "blind." That is, all petrographic observations were made without knowledge of the ceramic type, precise provenience, or NAA status of any specimen, and none of the quantitative data, even for individual thin sections, were tabulated until all specimens were analyzed.

Once the petrographic observations had been completed and the data tabulated, the next step was to establish the compositional parameters of the "local" ceramics. The preponderance of ceramics from Pinson Mounds are similar to those described for the Miller culture to the south, that is, have sand temper and fabric-marked, corded, and plain surfaces (e.g., Cotter 1950; Mainfort and Chapman 1994). We therefore employed "the criterion of abundance" (e.g., Bishop 1980:48; Rands and Bishop 1980:20; Zedeno 1994:51) to identify 26 sherds that meet these criteria and thus have a high probability of being local products. These sherds include 14 from Pinson Mounds and 12 from nearby Middle Woodland habitation sites (Figure 3). It is believed that each of these sherds derives from a separate vessel.

Table 1 presents the composition of these 26 vessels, recorded quantitatively as percent matrix, percent silt (i.e., all mineral inclusions ranging in size from .002 to .0625 mm), and percent sand (i.e., all mineral inclusions larger in maximum diameter than .0625 mm). A sand-size index is also recorded for each thin section. This particular index is presented as an ordinal scale ranging in value from 1 to 5. It was computed for each thin section by assigning a number to all sand-size grains recorded during point counting, based on maximum diameters, as follows: (1) .0625–.249 mm; (2) .25–.499 mm; (3) .50–.99 mm; (4) 1.00–1.99 mm; (5) >2.00 mm. The index itself is a single number that is the mean of all measured grains for each thin section. Incidental grains of grog were observed in five of the 26 thin sections recorded in Table 1, but in none of these cases did their frequency reach the 1 percent level of body composition. They are excluded from the compositional values in Table 1, but their presence is denoted by an asterisk.

While sherds such as these are commonly referred to as "sand tempered" (i.e.,

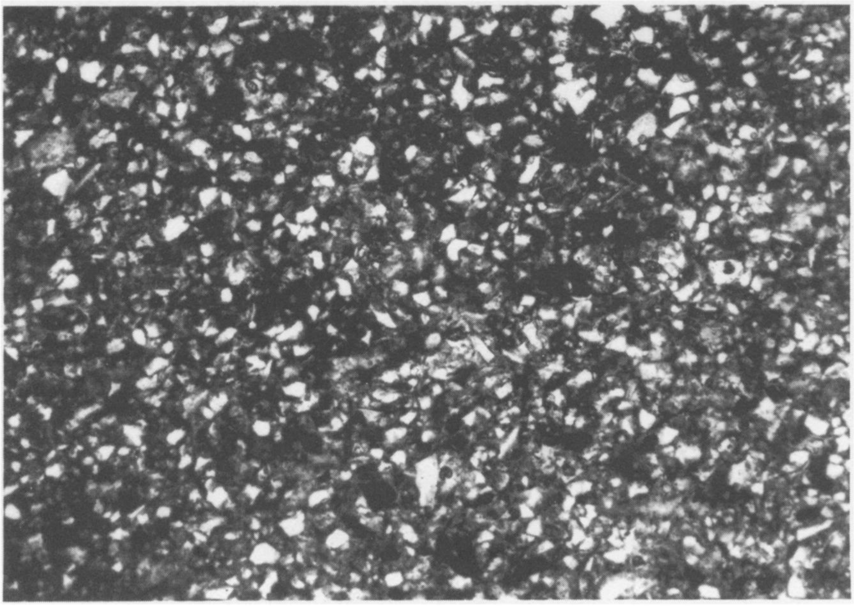

Figure 3. Photomicrograph of local Furrs Cordmarked vessel 40-86. Sand temper; sand-size index=1.02; viewed under plane-polarized light at 10X magnification. Scale=.225 mm for largest grain. NAA Group 3B.

are dominated by monocrystalline quartz inclusions), it is presently unknown whether Pinson-area potters added sand grains intentionally to clays in the process of ceramic production or simply selected appropriately sandy clays (cf. Mainfort and Chapman 1994:149). Distinguishing the two alternatives is important because efforts to match vessel compositions with natural sediments will be futile if sands truly were added as temper. Detailed comparisons of thin sections of local vessels and local sediments are required to resolve this issue, but in the current study such efforts proved to be inconclusive, as we discuss below. Since natural sands cannot be reliably distinguished from temper (i.e., human additives) in the "local" Pinson ceramics, the petrographic characterization of these vessels represents their *body*, that is, all mineral inclusions, whether natural or humanly added (see Stoltman 1991:109–110, 2001:304–305).

Because qualitative (i.e., surface finish and sand temper) rather than quantitative compositional criteria were the primary bases for identifying these 26 vessels as local products, the integrity of the resultant group in quantitative terms merits further scrutiny. After all, it is entirely possible that one or more of these vessels were imported from elsewhere within the same cultural province. Because there is no a priori way to know how much variability exists within any ceramic-making community, it seems reasonable and prudent to examine the variability of the current sample and attempt explicitly to assess its integrity.

Table 1. Body Compositions for "Local" Vessels Recovered at or Near Pinson Based on Petrographic Analysis.

Thin Section/ NAA Nos.	*Type*	*% Matrix*	*% Silt*	*% Sand*	*Sand Size Index*	*NAA Group*
Pinson						
40-43/—	Furrs Cordmarked	73	7	20	1.09	
40-44/—	Furrs Cordmarked	80	7	13	1.16	
40-46/—	Furrs Cordmarked	69	9	22	1.63	
40-50/—	Furrs Cordmarked	82	7	11	1.00	
40-51/—	Furrs Cordmarked	68	6	26	1.66	
40-52/—	Furrs Cordmarked	78	2	20	1.58	
40-64/PM-0063	Furrs Cordmarked	67	9	24	1.43	unassigned
40-88/PM-0021	Furrs Cordmarked	84	2	14	1.78	1
40-89/PM-0022	Furrs Cordmarked*	81	2	17	1.85	1
40-90/PM-0089	Furrs Cordmarked	71	6	23	1.05	4
40-45/—	Baldwin Plain	70	8	22	1.63	
40-48/—	Baldwin Plain	72	5	23	1.49	
40-47/—	Saltillo Fabric Imp	**60-**	3	**37+**	1.83	
40-91/PM-0110	Saltillo Fabric Imp	72	11	17	1.88	unassigned
Mean (N=14), Pinson		73.4±6.2	6.0±2.9	20.6±6.5	1.50±.31	
Mean (N=13) (vessel 40-47 excluded)		74.4±5.8	6.2±2.9	19.4±4.6	1.48±.31	
Near-Pinson sites						
40-53/—	Furrs Cordmarked	81	9	10	1.17	
40-55/—	Furrs Cordmarked	72	10	18	1.52	
40-79/PM-0142	Furrs Cordmarked	65	6	29	1.77	3A
40-85/PM-0007	Furrs Cordmarked	75	8	17	1.14	3A
40-86/PM-0011	Furrs Cordmarked	76	9	15	1.02	3B
40-94/PM-0154	Furrs Cordmarked*	88	6	6	1.06	4
40-54/—	Baldwin Plain*	79	6	15	1.66	
40-80/PM-0143	Saltillo Fabric Imp	72	6	22	1.68	3B
40-92/PM-0137	Saltillo Fabric Imp	64	7	29	1.60	3A
40-93/PM-0145	Saltillo Fabric Imp	71	8	21	1.60	unassigned
40-76/PM-0136	eroded*	76	7	17	1.86	3B
40-87/PM-0012B	eroded*	86	9	5	1.00	3B
Mean (N=12), Near-Pinson		75.4±7.4	7.6±1.4	17.0±7.7	1.42±.32	
Grand mean (N=26)		74.3±7.0	7.4±2.5	19.0±7.2	1.47±.31	
Adjusted grand mean (N=25, vessel 40-47 excluded)		74.9±6.5	6.9±2.4	18.2±6.3	1.45±.31	
2-sigma range (N=25)		61.9–87.9	2.1–11.7	5.6–30.8	1.00–2.07	

Bold font denotes values above [+] or below [-] 2 standard deviations from grand mean
* Denotes vessels with trace amounts of grog, i.e., less than 1 percent

Using the two-sigma (i.e., 95 percent probability) standard, we can take a position that is explicit, conservative, and reasonable in suggesting that those vessels with compositional values beyond two standard deviations of the grand mean of the 26 vessels merit serious consideration as nonlocal products. Applying this standard to Table 1, it can be seen that all body values for 25 of the 26 vessels fall comfortably within the two-sigma limits. The sole exception, vessel 40-47, is so sandy that it is considered a possible import and excluded from the "local" vessels. The adjusted grand mean recorded in Table 1, then, is based on 25 vessels accepted as "local" and is henceforth employed as a working definition of the range of compositional variation for ceramics that were produced within a 30-km radius of Pinson Mounds during Middle Woodland times.

Utilizing this working definition of locally manufactured ceramics, we next compared these values to those of four local sediment samples (all of which were also included in the NAA) to ascertain if vessel compositions could be matched with specific local clays. Table 2 records the body compositions for two fired-clay samples recovered during archaeological excavations at Pinson Mounds as well as two "raw" soil samples collected from nearby nonarchaeological contexts. While the local derivation of these clays is hardly in doubt, it can be seen from Table 2 that none matches the "local" ceramic vessels from Pinson Mounds and nearby sites. The conclusion that these clays were not those used in ceramic manufacture at Pinson Mounds is consistent with the NAA, which relegated three of the four to the "Unassigned" category (Table 2). Until a wider range of local sediments is analyzed, we are left to speculate about which specific local clays were used in pottery manufacture and whether or not the local ceramics were truly sand tempered.

The next question we considered was whether any discernible differences in composition could be recognized among the various sites in the sample. Because the 12 non-Pinson vessels in Table 1 derive from 11 different sites, the sample was clearly inadequate for detailed site-to-site comparisons. However, by pooling the 12 non-Pinson vessels into a single category, we attempted to address the question of whether the ceramic products from the Pinson site, at least, were identifiable within its regional context. As can be seen from Table 1, the compositional properties of the ceramics from Pinson Mounds are so similar to those of the nearby habitation sites that they cannot be discriminated objectively. At least

Table 2. Body Compositions for Soil Samples from the Pinson Area Based on Petrographic Analysis.

Thin Section/ NAA Nos.	*Type*	*% Matrix*	*% Silt*	*% Sand*	*Sand Size Index*	*NAA Group*
Pinson						
40-74/PM-0006	burned clay	74	**20+**	6	1.85	3B
40-75/PM-0097	fired clay	70	**17+**	13	1.96	unassigned
Near Pinson						
40-83/PM-0001	clay sample	69	**14+**	17	1.71	unassigned
40-84/PM-0003	clay Sample	**43-**	3	**54+**	1.79	unassigned
2-sigma range for local vessels (N=25)		61.9–87.9	2.1–11.7	5.6–30.8	1.00–2.07	

Bold font denotes values above [+] or below [-] 2 standard deviations from grand mean of the 25 "local" vessels with the present data, the results of petrographic analysis support the NAA findings in suggesting that the smallest spatial scale at which ceramic products in and around Pinson Mounds can be recognized is no smaller than the locality or region.

We can now consider the remaining 22 sherds included in the petrographic analysis. These have been divided into two groups: those tempered with materials other than sand (Table 3) and those that have "sand temper" but are otherwise characterized by nonlocal stylistic properties of decoration or surface finish (Table 4). For the 11 sherds tempered with materials other than sand (each of which is considered a separate vessel), the relevant compositional data are presented in Table 3. During point counting, individual temper grains were identified and measured separately from natural sand grains (see Stoltman 1991:111 for a description of this procedure). Their percentages and size indices are recorded separately in Table 3. But in order to render the compositional data for these vessels comparable to those of the other vessels in the study, the counts of temper grains and the natural sands were combined in the "% Sand*" column in Table 3. This table, then, records the body compositions of all the non-sand-tempered vessels in precisely the same format (i.e., percent matrix, silt, and sand, along with sand-size indices) used in Tables 1, 2, and 4 for the other samples in this study.

Four of the vessels in Table 3 may be regarded, with a high degree of probability, as nonlocal based on the presence of clearly exotic tempers. Three of these vessels—nos. 40-61 (Figure 2, lower right), 40-70 (Figure 4d), and 40-81 (Figure 5b) are tempered with metamorphic crystalline rocks, while vessel 40-65 (Figure 2, bottom row middle) has leached limestone temper (accompanied by chert). None of these rock types occurs within a 50-km radius of the Pinson Mounds site (e.g., Floyd 1965). Despite the nonlocal character of the tempers in these four vessels, it is noteworthy that three of them were assigned to local NAA groups, with only vessel 40-61 "Unassigned" (Table 3).

The remaining seven vessels in Table 3 have grog, bone, or organic tempers, all uncommon at Pinson Mounds. Unlike the crystalline rocks, whose exotic status at Pinson Mounds is demonstrable, these materials *could* be of local origin, so their use alone does not provide incontrovertible evidence of nonlocal derivation. However, other variables provide important evidence relevant to the issue of local versus nonlocal production of these vessels.

Besides temper, two additional independent variables readily classifiable as local or nonlocal can be employed to evaluate the status of these vessels: (1) surface finish/decoration and (2) body composition. Two of these seven vessels—nos. 40-69 and 40-72—are not only characterized by potentially exotic tempers (bone and grog, respectively), but they also have "nonlocal" states for both decoration (the former is incised, the latter check stamped) and body composition (the former is much siltier than the local vessels, while the latter, with a sand size index of 2.31, has uniquely large quartz inclusions; Table 3). Along with the four rock-tempered vessels, we consider it highly probable that these two vessels are intrusive. One other vessel merits such consideration, vessel 40-66. This vessel is red-filmed, a highly unusual surface finish at Pinson Mounds,

Table 3. Body Compositions for Eleven Non-Sand-Tempered Vessels Recovered at and Near Pinson Mounds.

Thin Section/ NAA Nos.	*Sand Size Type*	*Temper % Matrix*	*% Silt*	*% Sand**	*Index***	*% Temper*	*Size Index*	*NAA Group*
Pinson								
40-61/PM-0060	untyped corded	**60-**	**16+**	24	1.27	16% quartzite	**4.36+**	unassigned
40-65/PM-0067	untyped corded	86	3	11	**0**	11% LS+chert	**3.36+**	4
40-66/PM-0068	Larto Red	72	11	17	1.10	10% grog	**4.00+**	3B
40-67/PM-0071	untyped plain	80	5	15	1.00	7% plant?	**3.50+**	4
40-69/PM-0113	untyped incised	69	**14+**	17	1.38	2% bone	**2.60+**	3A
40-70/PM-0118	untyped check st	**58+**	6	**36+**	1.22	23% quartzite	**2.90+**	3A
40-72/PM-0056	untyped check st	64	7	29	**2.31+**	1% grog	**4.00+**	3A
Near Pinson sites								
40-77/PM-0138	eroded sherd	69	8	23	1.38	9% grog	**3.50+**	3B
40-78/PM-0135	eroded sherd	82	8	10	1.36	2% grog	**4.00+**	4
40-81/PM-0151	untyped fabric imp	73	3	24	1.50	19% metam rk	**3.12+**	3B
40-82/PM-0160	eroded sherd	76	7	17	1.31	6% grog	**3.67+**	3B
2-sigma range for local vessels (N=25)		61.9–87.9	2.1–11.7	5.6–30.8	1.00–2.07			

Bold font denotes values above [+] or below [-] 2 standard deviations from grand mean of the 25 "local" vessels

* Includes all sand-sized inclusions both natural and human additives; ** pertains only to natural sands

Table 4. Body Compositional Values for Eleven "Sand-Tempered" Sherds Recovered at Pinson Mounds That Are Stylistically Nonlocal.

Thin Section/ NAA Nos.	*Type*	*% Matrix*	*% Silt*	*% Sand*	*Sand Size Index*	*NAA Group*
40-49/—	untypedsimple st	**61-**	7	**32+**	1.45	
40-56/PM-0013	Swift Cr Comp St	65	6	29	1.44	3A
40-57/PM-0014	Swift Cr Comp St	65	11	24	1.42	3A
40-58/PM-0015	Swift Cr Comp St	65	9	26	1.55	3A
40-59/PM-0016	Swift Cr Comp St	**58-**	**13+**	29	1.46	3A
40-60/PM-0017	burnished	65	7	28	1.45	3B
40-62/PM-0061	McLeod Simple St	70	6	24	1.52	3B
40-63/PM-0062	McLeod Simple St	73	5	22	1.23	3B
40-68/PM-0084	Marksville Stamped	70	7	23	1.93	3A
40-71/PM-0124	Marksville Stamped*	**59-**	**13+**	28	1.04	3A
40-73/PM-0059	untyped check st	74	7	19	1.69	4
2-sigma range for local vessels (N=25)		61.9–87.9	2.1–11.7	5.6–30.8	1.00–2.07	

Bold font denotes values above [+] or below [-] 2 standard deviations from grand mean of the 25 "local" vessels; * denotes vessel with a trace of bone temper; Nos. 40-56, 57, 58, and 59 are believed to derive from a single vessel

and is robustly tempered with grog (10 percent, the highest incidence of grog observed in this study), some of which is itself tempered with grog (Figure 5a). The latter property is an unlikely local characteristic considering the paucity of grog temper in local ceramics.

Since the other four vessels listed in Table 3—nos. 40-67, 40-77, 40-78, and 40-82—are characterized by tempers that are possibly, but not certainly, exotic, we regard their local status as equivocal. Vessel 40-67, an untyped plain vessel, is unique in possessing leached or degraded biogenic temper; the cellular structure in a few of the voids that characterize this vessel appear to be of plant origin (Figure 6).

Table 4 presents a compilation of body data for 11 sherds (believed to represent eight vessels) from the Pinson Mounds site that are "sand tempered" but are suspected on stylistic grounds of having been imported. Because of the stylistic diversity of these sherds, they are believed to have multiple nonlocal origins—Swift Creek types from the east, McLeod types from the south, and Marksville types from the west (e.g., Mainfort 1986:35–46). The body compositions of two stamped vessels have values beyond the two-sigma range of the local standard—40-49 is sandier while 40-71 is siltier—and thus appear to be nonlocal. In addition, vessel 40-71 is distinctive in having trace amounts of bone scattered in its paste. At least four of the typologically nonlocal vessels listed in Table 4—Nos. 40-60, 40-62, 40-63, and 40-68—appear to have "local" body compositions.

The complicated-stamped sherds are the most distinctive and unexpected of the possible exotics from Pinson Mounds, since western Tennessee is well beyond the suspected Swift Creek heartland in Georgia (Mainfort et al. 1997:64–65; Williams and Elliot 1998:6). The four sherds included in Table 4 were selected from a larger sample of 74 recovered from the Duck's Nest sector of the

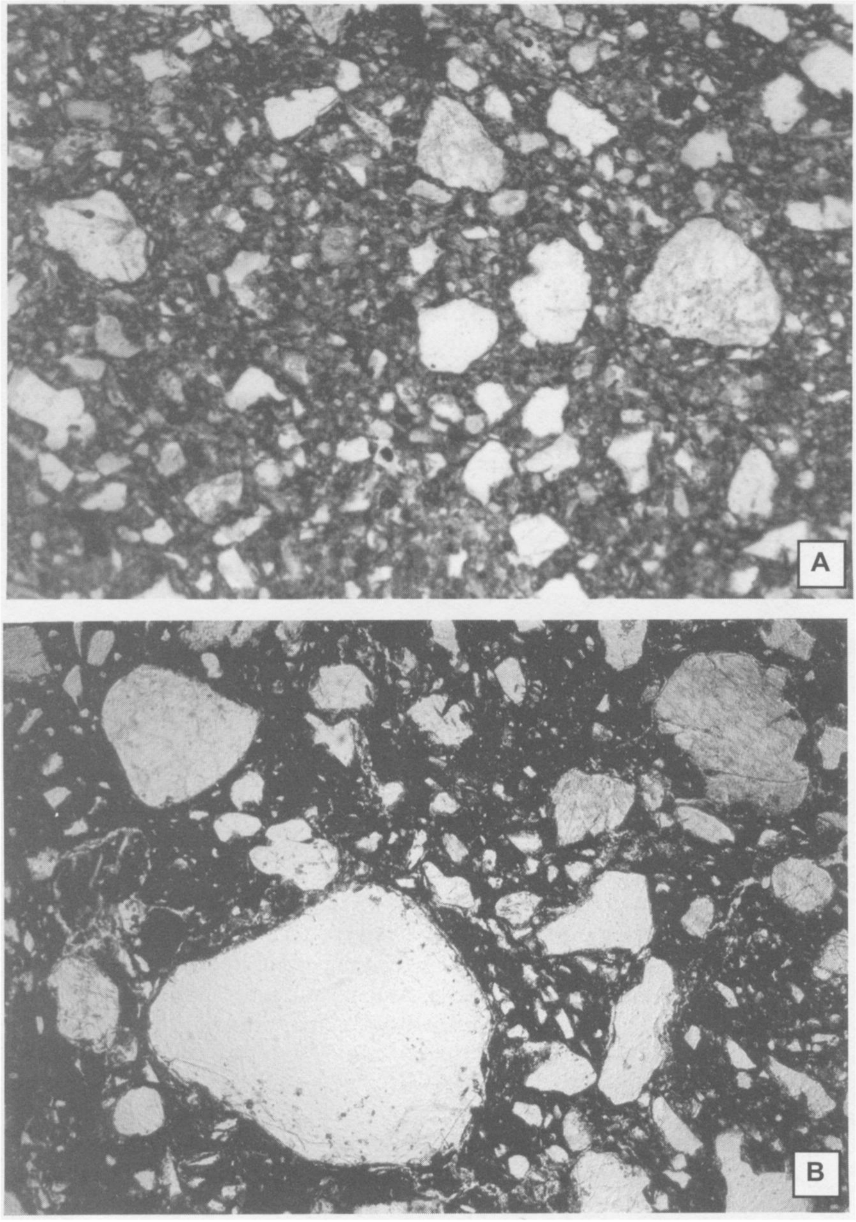

Figure 4. Photomicrographs of four presumably exotic vessels, all viewed under plane-polarized light at 10X magnification. All were assigned to NAA Group 3A. a, Vessel 40-59; sand-tempered, complicated-stamped vessel; sand-size index=1.46; largest quartz grain=.625 mm; b, Vessel 40-72; check-stamped vessel with 1 percent grog temper (none visible in this photo); note coarseness of sand; sand-size index=2.31; largest quartz grain=1.125 mm.

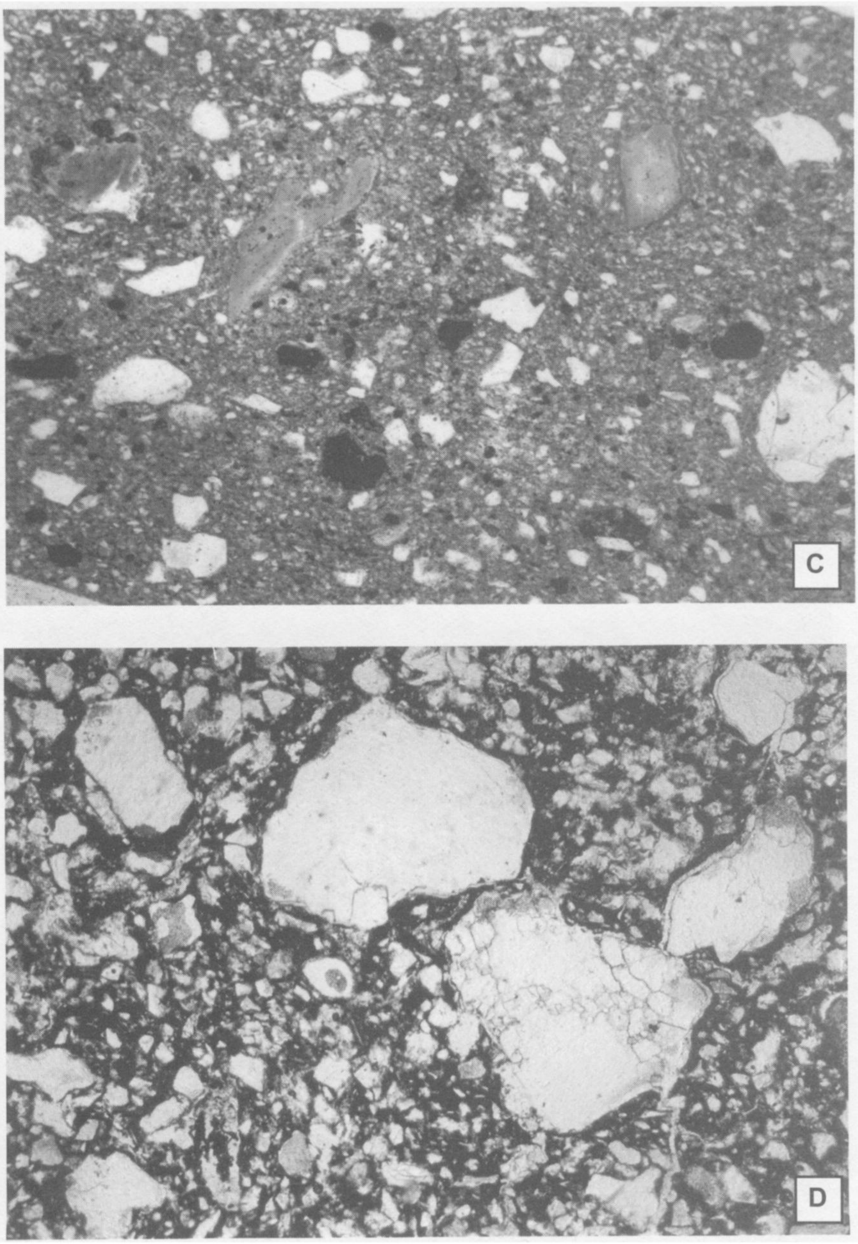

Figure 4 continued. c, Vessel 40-69; incised vessel with bone temper—three grains (with black dots=biogenic structure) visible across the top half of the field of view. Longest bone=.85 mm; d, Vessel 40-70; check-stamped vessel with quartzite temper (note polycrystalline structure of the three largest grains). Largest quartzite grain=1.075 mm.

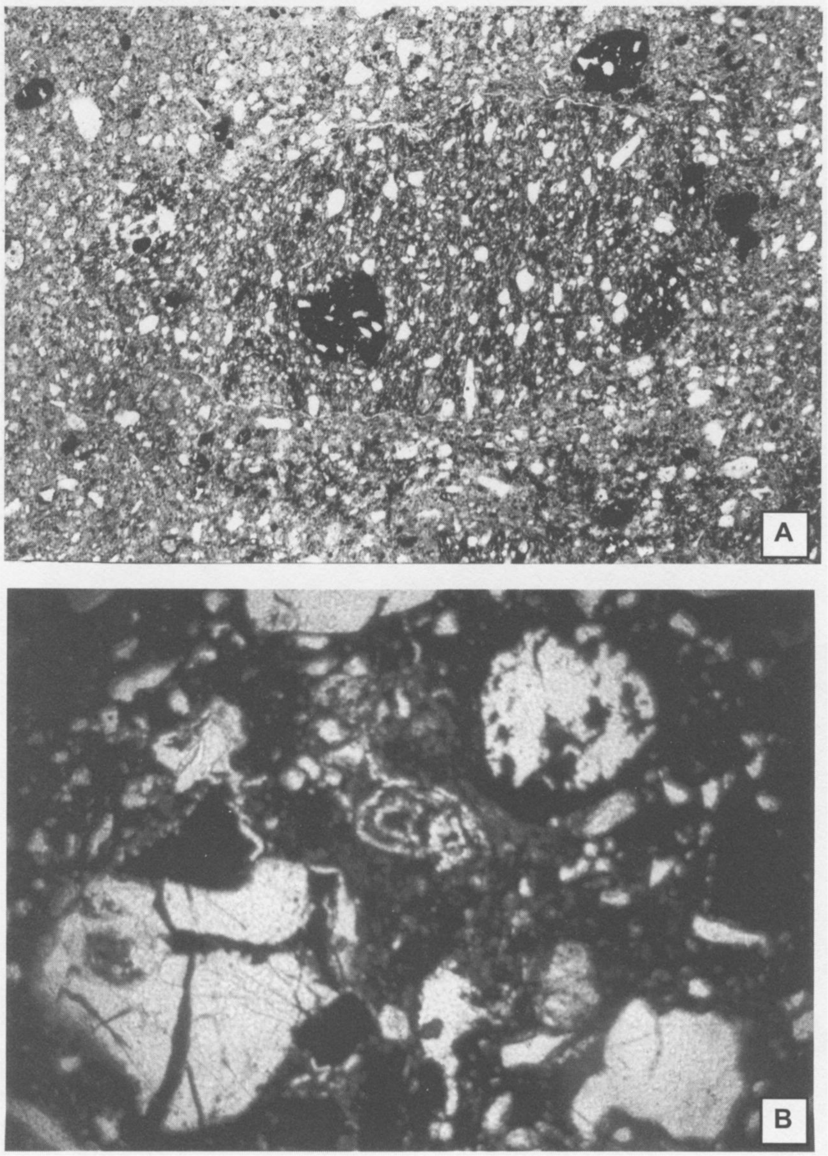

Figure 5. Photomicrographs of two presumably exotic vessels viewed in plane-polarized light at 10X magnification; both assigned to NAA Group 3B. a, Vessel 40-66; red-filmed vessel with grog temper. Large grog-tempered grog grain (2.45 mm long) dominates the center. Marginal fissure (parting rim), denser paste, and different density and orientation of sand inclusions define the grog grain; the two darkest areas, one inside and one outside the large grog grain are iron stains; a grog grain inside the larger grog grain is located at the lower right edge of the larger grain. b, Vessel 40-81; untyped fabric-impressed vessel tempered with a metamorphic rock composed primarily of strained quartz and an unidentified opaque mineral. Largest temper grain=1.4 mm.

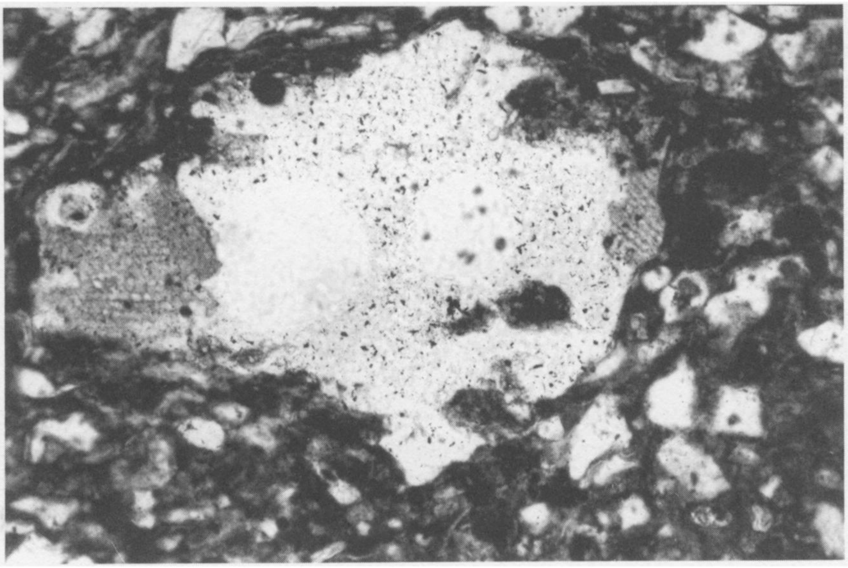

Figure 6. Photomicrograph of vessel 40-67. Note large central void with remnants of biogenic (unidentified plant) temper at each end. Maximum dimension of this grain is 1.1 mm. Viewed under plane-polarized light at 25X magnification. NAA Group 4.

Pinson Mounds site and are believed to derive from one or, possibly, two vessels (Mainfort 1986:46). Compositionally, the four sherds are uniform enough to suggest a common derivation, probably even from a single vessel (this is not the case, for example, for the two Marksville Stamped sherds in Table 4). The collective body composition for these four sherds is 63 percent matrix, 10 percent silt, and 27 percent sand, all values falling above one, but below two, standard deviations from the "local" mean, and is consistent with the view of their local production. However, that one of these sherds (40-59) is significantly siltier than the "local" mean suggests that the possibility of a nonlocal origin for these stylistically distinctive sherds should not be completely discounted.

Relevant to the issue of the nonlocal derivation of these complicated-stamped sherds, it should be noted that the senior author has analyzed a substantial number of thin sections of Swift Creek Complicated Stamped vessels from Georgia and, for the most part, they do *not* provide close matches to the Pinson vessels (Stoltman and Snow 1998). Not included in that analysis, however, were 10 vessels from Mandeville, an important Middle Woodland site in southwest Georgia (Smith 1979), whose mean body values—65.1±8.1 percent matrix, 6.3±3.6 percent silt, 28.6±7.6 percent sand—show close similarities to the complicated-stamped sherds from Pinson Mounds, thus keeping open the possibility of external derivation.

In sum, petrographic observations of 48 Pinson-area sherds (as well as four soil samples) conducted independently of the NAA suggest that at least nine of the specimens likely were nonlocal products. Since local clays used in pottery manufacture at Pinson Mounds and nearby sites have not yet been identified (Mainfort et al. 1997:64), the compositional properties of locally produced ceramics were determined from petrographic observations of 25 vessels whose local manufacture could be accepted with a high degree of probability based on context and typology. By employing these body values at a conservative two-sigma level, in combination with the independent variables of surface finish/decoration and temper type, we then assessed the probability that the other 22 sherds, representing a minimum of 19 vessels, could be of nonlocal derivation. As a result, we conclude that at least nine of these vessels are strong candidates for nonlocal products: four vessels with demonstrably nonlocal crystalline rock tempers (40-61, 40-65, 40-70, and 40-81; Figures 4d and 5b); one red-slipped vessel with grog-tempered grog (no. 40-66; Figure 5a); two stylistically nonlocal vessels (incised and check stamped) with body compositions outside the "local" two-sigma range (nos. 40-69 and 40-72; Figure 4b); and two of the "sand-tempered" vessels that are characterized by nonlocal states for both decoration (stamping) and body composition (nos. 40-49 and 40-71). Interestingly, the most stylistically exotic vessel from Pinson Mounds, the Swift Creek Complicated Stamped vessel (Figure 2, middle row), which is represented by four thin-sectioned sherds (nos. 40-56, 57, 58, 59) in this study, has a body composition that provides suggestive but not conclusive evidence of nonlocal status.

Besides the demonstrably exotic crystalline rock tempers in four vessels, other qualitatively unusual, thus potentially exotic, tempers (i.e., grog, bone, and plant) were observed in eight vessels. Since such materials are potentially available in any locality, their mere presence is insufficient evidence of nonlocal derivation. The current study suggests that grog may occur in quantities ranging from trace amounts to 9 percent in locally produced vessels (e.g., nos. 40-77, 40-78, and 40-82). This conclusion must be considered tentative, however, because all three of the aforementioned vessels were represented by eroded sherds whose stylistic character could not be assessed (Table 4). Two other vessels with more than trace amounts of grog (nos. 40-66 and 40-72) were included above among the strong candidates for nonlocal status, based on multiple lines of evidence. The single plant-tempered (?) vessel (no. 40-67; Figure 6) is unique in this study but cannot otherwise be categorized as nonlocal. It is perhaps significant that the two vessels with small amounts of bone inclusions (40-69 and 40-71; Figure 4c) both are characterized by nonlocal compositions and decoration.

Comparing the Findings of Petrography and Neutron Activation Analysis

In order to assess the significance of the different findings of NAA and petrographic analysis in the Pinson Mounds study, one must not lose sight of the fact that the elements contained in an NAA inventory of pottery represent the *bulk composition* of the samples analyzed (e.g., Neff et al. 1996), whereas the mineral-rock inventory of a petrographic analysis represents primarily the non-clay (i.e., silt-sand-gravel) fraction of the samples. To appreciate the relevance of these differences as they pertain to the issues of ceramic production and exchange, it is important to be aware of the complexity and artificial nature of the composition of archaeological ceramics. The chemical makeup of this humanly created mixture derives from at least five independent sources: (1) the clayey sediments used in ceramic manufacture, including all natural inclusions of silt, sand, organics, and so on; (2) any "temper" intentionally added by the potters; (3) water used in ceramic manufacture, which commonly contains soluble salts of such elements as sodium, potassium, calcium, magnesium, and iron; (4) any remnants of vessel contents that may originally have been stored, heated, or transported in the containers; and (5) postdepositional alteration, or diagenesis (e.g., Arnold et al. 1991; Bishop 1980; Bishop et al. 1982:295–296; Mainfort et al. 1997:47).

An elemental inventory based on NAA can receive input from all five of these sources, with the relative contributions of each being undeterminable. By contrast, a petrographic inventory records grains that derive only from the first two: natural inclusions in the clayey sediments and temper. These two kinds of inclusions frequently are conflated in petrographic analyses, resulting in an outcome analogous to NAA's bulk composition (but without input from the other three sources, which normally involve elemental exchanges that are beyond the detection levels of petrography). On the other hand, petrography has the unique potential to move beyond bulk composition. By taking careful steps to distinguish natural inclusions from temper, petrography is capable of identifying separate sources for clayey sediments and tempers (e.g., Stoltman 1989, 1991, 1999, 2001), although, as noted previously, when dealing with "sand-tempered" ceramics, the distinction between paste and body may be impossible to make objectively. Such was the case in this study, so that body was the physical parameter employed to characterize vessel compositions.

"Sand temper" of the sort observed in the Pinson Mounds ceramics also presents problems for NAA. Ten to 30 percent of the volume of most of these vessels comprises sand-size inclusions that are preponderantly (over 88 percent) monomineralic grains of quartz. Since the main compositional elements of quartz, silicon, and oxygen are not detected by NAA, such grains act as diluents that lower the percentages of the other elements (Bishop 1980:49–50). Thus, differential amounts of quartz in pottery, whether natural, temper, or both, will have the effect of altering elemental signatures, even in cases of uniform clay composition. How much variability quartz in differing amounts can introduce into NA analyses of ceramics is a complex issue that remains to be addressed empirically. Surely it cannot be considered in isolation, because the chemical character of the clay fraction also is bound to be important—some clays will be more susceptible than others to the effects of dilution.

Considering these differences between the output of the two approaches, we saw the present study as an ideal opportunity to attempt a critical evaluation of the relative effectiveness of NAA and petrography to address issues of ceramic production and exchange. Our initial expectation was that because the two approaches are unparalleled in their proven effectiveness to "do their jobs"—namely, identifying elements versus identifying rocks and minerals—their application to a common prehistoric pottery data set would produce different but complementary results. Let us consider this expectation in light of the two studies of Pinson Mounds ceramics.

NAA Findings

With regard to the Pinson data set, the main NAA findings may be viewed as reflecting two distinct geographic scales. The first and most fundamental conclusion, presented at the interregional scale, is that "principal components analysis (PCA) of the variance-covariance matrix of the entire data set clearly differentiated the Georgia ceramic samples (p=<.05) from the Tennessee samples, including the Swift Creek Complicated Stamped sherds from Pinson Mounds" (Mainfort et al. 1997:47). In other words, the 164 Middle Woodland pottery and soil samples recovered in western Tennessee have different chemical signatures from the six Middle Woodland sherds recovered in north and central Georgia.

Moving next to the intraregional scale, "extensive" statistical manipulations of 154 Tennessee samples (10 were deleted as "outliers" from the original 164) resulted in the recognition of "three main Pinson Mounds compositional groups, 3A, 3B, and 4" (Mainfort et al. 1997:47). These three groups contain 50, 41, and 30 samples, respectively, totaling 121 specimens. The 33 samples excluded from the three groups are recorded as "Unassigned," with 16 of these further designated "Transitional Between Groups 3A and 3B" (Mainfort et al. 1997:54–55). Thus, in this case the cost of recognizing the three chemical groups was to sacrifice further consideration of 26 percent of the original 164 Tennessee samples.

Subsequent analysis of the distribution of the three main intra-Tennessee compositional groups (the initial 10 "outliers" plus the 33 "Unassigned" are no longer considered) revealed no clear cultural patterning. Rather, all three groups occurred at multiple sites within the region, while at Pinson Mounds, "none of the identified compositional groups is exclusively associated with specific ceramic surface treatments or specific proveniences within the site" (Mainfort et al. 1997:61). Thus, once defined, the recognized groups provide no insights that are not already contained in the first part of the study, namely, that the chemical signature of pottery found in Tennessee differs from that of pottery found in Georgia.

The explanation offered for the "demonstrated mixture of compositional groups at Pinson and nearby sites" is that "locally produced pottery was a readily transported commodity in the Pinson area during the Middle Woodland period" (Mainfort et al. 1997:59). An alternative interpretation for the apparently random distribution of the NAA groups that we feel must also be considered is that these groups are more a reflection of the analysis than of prehistoric behavior. Whatever the meaning of the three compositional groups, together they constitute the primary basis for the most significant conclusion of the NAA study, expressed as follows: "Of the 154 pottery samples analyzed, all samples submitted from Pinson Mounds and nearby sites are probably of local origin" (Mainfort et al. 1997:62).

This view is clearly in marked contrast to Mainfort's earlier style-based observation that there were "10 unquestionable non-local vessel fragments in the Duck's Nest sector" (Mainfort 1986:46; see also Mainfort et al. 1997:64–65). It also runs contrary to the findings of the current petrographic analysis, which identified at least nine of the 35 thin-sectioned sherds also included in the NAA study as strong candidates for imported vessels. It is also noteworthy that, on petrographic grounds, we have identified five vessels as "local" that were excluded from local status in the NAA study either as "outliers" (Vessels 40-88 and 40-89; see Table 1) or as "unassigned" (Vessels 40-64, 40-91, and 40-93; see Table 1). In light of these contradictory findings, it is difficult to see the two studies as having produced equally valid results.

These discordant findings—especially the NAA classification as "local" of several vessels that contain undeniably nonlocal materials—lead us to postulate that NAA has important limitations in its ability to reliably identify nonlocal ceramic vessels from within the large data sets to which the approach is typically applied. We attribute this to three principal factors: (1) the utilization of complex, multivariate statistics that carry the high cost of cluster recognition based on only a portion of the total data set after first deleting a substantial minority of the analyzed samples (26 percent in this case); (2) an inability to isolate and, thus, compensate for the effects introduced by inclusions into the bulk compositional ceramic signatures produced by NAA; and (3) a general underappreciation of the importance of diagenesis in producing NAA ceramic signatures.

The Role of Statistics

Scale is an important issue when considering the appropriateness of the statistical procedures typically applied to outputs of NA analyses of ceramics. As has been stressed in a number of such studies (e.g., Arnold et al. 1991; Steponaitis et al. 1996), the most appropriate application of NAA to the problem of ceramic source determination is at the regional rather than the site level. In such studies, a large number of ceramic vessels are analyzed, usually hundreds, and each specimen is then characterized in terms of percentages of a large number of elements—33 were recorded in the Pinson analysis (see Baxter and Jackson 2001 for a critique of the "more is better" approach to element selection for NAA).

The use of multivariate statistics to analyze such data is, of course, entirely appropriate but not without problems. An obvious constraint imposed by publishing in journals and books is that graphic depictions of data must be presented in two-dimensional space, but "Group membership cannot... be reduced to a consideration of two dimensions alone when variability was measured along multiple dimensions" (Arnold et al. 1991:86). Despite this caveat, bivariate plots are typically used to portray NAA data (e.g., Hegmon et al. 1997:455; Steponaitis et al. 1996:561; Strazicich 1998:265), as they were in the Pinson study (Mainfort et al. 1997:48–49).

The goal of the statistical analysis of the NAA results is to expose the underlying structure that is presumed to reside in such data sets, that is, to reveal a grouping or cluster of samples that share certain chemical properties and thus can serve to define a regional ceramic signature. In the Pinson study, the results of the first principal components analysis produced an amorphous, shotgun-blast data array (Figure 7) that required further statistical manipulation to reveal the three chemical groupings. As is true generally with the application of multivariate statistics in NAA studies, the cost of recognizing chemical groups or clusters invariably involves the exclusion of some samples as "outliers," "unassigned," or "ungrouped." In the Pinson study, 43 of the original sample of 164 Tennessee sherds and soil samples, or 26 percent, were excluded in the process of identifying the three main local compositional groups (Mainfort et al. 1997:47, 54). Similarly, in a recent NAA study of 186 Mississippian vessels from across the Southeast, Steponaitis et al. (1996) classed 30 percent of their sample (56 sherds) as "ungrouped" in the process of defining four major NAA groups totaling 130 sherds.

The exclusion of a diverse set of over 25 percent of the samples in the process of group or cluster definition is enough alone to prompt questions about whether the clusters were created or discovered, but there are additional concerns with respect to the Pinson study. As noted previously, included among the 43 deleted

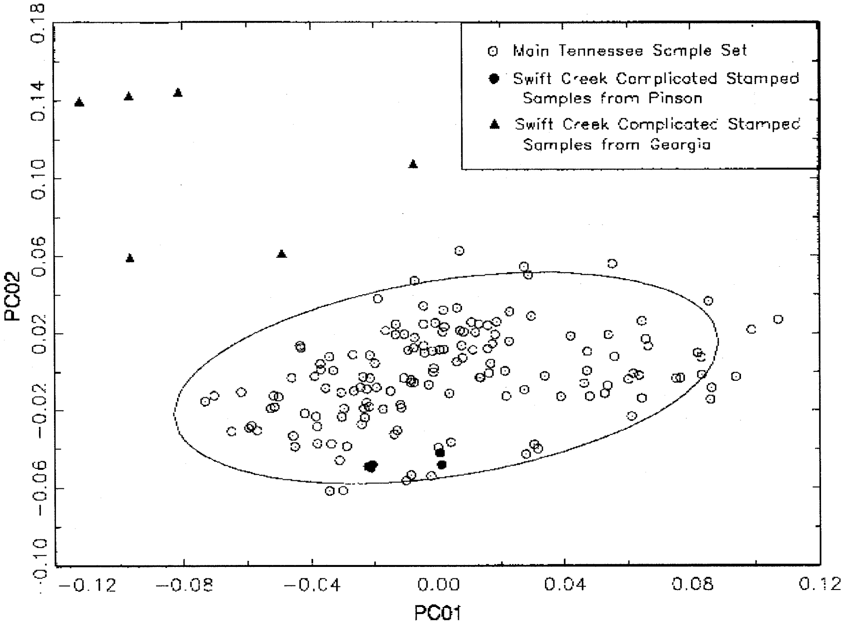

Figure 7. Plot of first two principal components of NAA data with outliers removed. Ellipse represents 90 percent confidence interval. Originally published in Mainfort et al. (1997).

samples are 16 classed as "Transitional Between Groups 3A and 3B" (Mainfort et al. 1997:54). Since these, along with the other 27 outlier and unassigned samples, are excluded from the sole bivariate plot portraying the three main chemical groups (Mainfort et al. 1997:Figure 4), it is perhaps no surprise that the three groups plot as fairly distinct (although definitely overlapping) clusters. Considering that the statistical manipulations to which the Pinson NAA data were subjected involved the progressive diminution of the sample from 164 to 154 to 121, we are reminded of the wise admonition of Jain and Dubes (1988:75) that "Clustering methods have a nasty habit of creating clusters in data even when no natural clusters exist, so hierarchies and clusterings must be viewed with extreme suspicion" (see also Baxter 1994:147 and Bishop and Neff 1989:62).

The Role of Inclusions

As is well known, inclusions, both natural and artificial, contribute importantly to elemental inventories of ceramics in two ways: (1) by directly adding new elements or increasing percentages of elements already present (especially by most minerals, rocks, and grog) and (2) by reducing the percentages of other elements through dilution (by quartz, including polycrystalline forms like quartzite and chert). The extent to which inclusions can affect elemental inventories depends on multiple variables, including their character and abundance in interaction with the chemical makeup of the particular clays of each sample as well as sample representativeness given the necessarily small portions of sherds ultimately submitted for NAA analysis (e.g., Arnold et al. 1978, 1991; Bishop 1980; Bishop et al. 1982; Neff et al. 1988, 1989).

While the capacity of inclusions to influence elemental inventories of ceramics is universally recognized, relatively little has been done to offset these effects. This is not an inconsequential problem, since the bulk chemical composition of *tempered* ceramics can rarely be expected to match any natural clays. In order to compensate for the effects of temper in the interpretation of NAA compositions, at least three approaches have been attempted: (1) the mathematical deletion or reduction of specific elements when shell is present as temper (Cogswell et al. 1998; Steponaitis et al. 1996), (2) sonic disaggregation to separate inclusions before NAA (Elam et al. 1992; Neff et al. 1996), and (3) estimating the chemical composition of local ceramics "analytically (not physically)" as a mixture of local clays and igneous rocks whose separate elemental compositions were previously determined (Hegmon et al. 1997). While admirable efforts, none of these approaches was used in the Pinson study or in the majority of other NA analyses of ceramics. As a result, it seems to us, there is a tendency to accept inclusions as a necessary inconvenience, sometimes referred to as "noise" (Bishop 1980:48), whose effects are then underestimated if not ignored outright. Notable examples of the latter tendency can be seen in the statement by Zedeno (1994:51) that "Instrumental Neutron Activation Analysis (INAA) identifies the chemical composition of clays used in the manufacture of ceramics" and in the discussion concerning the recognition of ceramic production zones by Rands and Bishop (1980:19–20), couched solely in terms of clays.

The tendency to underestimate the contributions of inclusions to the formation of elemental inventories of ceramics has no doubt been nurtured by a paucity of robust empirical research into the problem. Two notable exceptions in this regard are the studies of Arnold et al. (1978) and Elam et al. (1992) in which independent NA analyses of clays and tempers were conducted. The two studies document that the elemental inventory of fired pottery (i.e., its bulk composition) differs from both the temper and the raw clays from which it was manufactured. Indeed, in comparing the chemical compositions of the coarse, fine, and bulk fractions for 40 sand-tempered vessels from Arizona, Elam et al. (1992:104–105) observed that the bulk composition more closely resembled the coarse fraction than the fine fraction of the sherds analyzed. The authors attribute this to an inability to remove all of the clay from the coarse fraction during sample preparation (Elam et al. 1992:105), but an equally plausible alternative seems to have been overlooked, namely, that the inclusions *do* make a significant contribution to the bulk chemical composition.

Further empirical research into this issue certainly is warranted. This could be expeditiously accomplished by preparing experimental test tiles using various carefully controlled mixtures of materials of previously determined composition—clays, quartz, and grit—then subjecting them to conventional NAA. In the absence of such research, thinking about the relative impact of inclusions on NAA signatures has rested heavily on two influential simulation studies in which varying amounts of a single temper type, volcanic ash, were added to two compositionally distinct clays (Neff et al. 1988, 1989). While undeniably valuable contributions, these studies have three important limitations: (1) the two clays were "chemically very distinct," thus placing an exceptionally heavy burden on the temper to close the chemical gap between them (Neff et al. 1988:164); (2) the use of only volcanic ash, a temper type of highly localized availability, renders uncertain the extensibility of this study to other, more common tempers; and (3) as purely mathematical simulations, they deserve empirical follow-up research before they are accorded unqualified acceptance. In sum, an adequate empirical basis is currently lacking for assessing the extent to which clays of differing composition may appear to overlap chemically as a result of differing amounts and combinations of inclusions. In the absence of such a foundation, especially in light of the observation of Neff et al. (1989:68) that "tempering may create as well as destroy compositional patterning in a group of tempered ceramics," we simply do not know how seriously to consider the possibility that various mixtures of clays and inclusions from two different places may overlap chemically within the context of an elemental analysis of sherds whose local versus nonlocal status is being investigated.

The existence of a substantial sample of Pinson-area sherds and soils for which both petrographic and NAA data are available provides an excellent context within which to attempt an assessment of the role of inclusions in the formation of chemical groupings. The frequencies and percentages of the 39 petrographic samples vis-à-vis the chemical groupings of the NA study are presented in Table

5. The two Group 1 samples, although assigned a formal group number in the NA study, were among the original 10 "outliers" excluded from further consideration after the first round of statistics because of "low probabilities of membership in the main Tennessee data set" (Mainfort et al. 1997:47). These samples are included here because our concern at this point is solely with the effects of inclusions in the formation of chemical groups, whether those groupings ultimately prove to be local or not.

As shown in Table 5, roughly one-quarter of the 164 samples from Tennessee that were subjected to NAA also were thin sectioned, and these 39 samples are distributed among the NAA groupings proportionally to the distribution of the NAA groups themselves. Tentatively adopting the enabling supposition that the current thin-section sample accurately represents the contents of each of the NAA groups, we now consider what light these data can shed on the role inclusions may have played in shaping the chemical content of the groupings.

Before comparing the two data sets directly, let us set down two expectations about the relationship between inclusions and chemical groups that can serve as guidelines for evaluating the results. First, all vessels with exotic, non-quartz tempers ought to occur either as outliers to the local chemical groups or in the unassigned category. This expectation is reasonable even if the tempers were imported but the vessels were made of local clays because the tempers should still be reflected in the NAA signature. Second, since local ceramics in this study contain predominantly quartz inclusions and are all presumably of the same age, any local (i.e., intraregional) groups should differ from one another primarily in terms of amounts of quartz inclusions, since clay resources and diagenesis ought to be more or less constant. Most of the thin section data relevant to the ensuing discussion are presented in Tables 1–4.

Turning first to the vessels with nonlocal tempers, there are four among the thin-sectioned specimens that have tempers of unquestionable nonlocal origin: Vessels 40-61 and 40-70 (both with metaquartzite), Vessel 40-65 (with leached limestone + chert), and Vessel 40-81 (with metamorphic rock). In addition, there are two vessels with bone inclusions (Vessels 40-69 and 40-71), one vessel with biogenic inclusions (Vessel 40-67), and eight vessels with grog inclusions that are characterized by potentially, but not certainly, exotic tempers (Vessels 40-66, 40-72, 40-76, 40-77, 40-78, 40-82, 40-89, and 40-94).

The four vessels with nonlocal rock tempers are scattered among four of the

Table 5. Frequencies and Percentages of NAA and Thin-Sectioned Samples as Distributed by NAA Groupings.

NAA Groupings	*f + % NAA Samples*	*f + % Thin Sections*
Group 1	2 (1%)	2 (5%)
Group 3A	50 (31%)	12 (31%)
Group 3B	41(25%)	12 (31%)
Group 4	30 (18%)	6 (15%)
Unassigned	41 (25%)	7 (18%)
Totals	164 (100%)	39 (100%)

five chemical groupings listed in Table 5, as follows: Vessel 40-70 in Group 3A; Vessel 40-81 in Group 3B; Vessel 40-65 in Group 4; and Vessel 40-61 in the unassigned category (Table 3). That three of these vessels were assigned to local groups and only one was placed in the unassigned group is surprising if the vessels were imported from elsewhere. One might argue that these vessels were made from local clays, which brings us back to the basic issue of the role of inclusions: why, if these vessels possess exotic tempers (*especially* if they were made from local clays), are they not chemically distinct from the purely sand-tempered local vessels?

The roles of grog, bone, and plant inclusions are difficult to evaluate in the current data set because their incidence is low—10 percent or less by volume in all samples—so that their chemical impact could be minimal. That all 11 of these vessels were assigned to the three main local groups (3A, 3B, and 4) and that none was unassigned may be taken as evidence either that temper was underrepresented in the NAA samples analyzed or, in the case of grog, that local sherds were used for temper. We find both of these possibilities unlikely in the case of Vessel 40-66, a stylistically unique red-filmed vessel with grog temper, some of which is also grog tempered (Figures 2 and 5a). This is also the only vessel with more grog (10 percent) than sand (7 percent). Everything about Vessel 40-66 appears to be nonlocal, yet it was assigned to NAA compositional Group 3B.

Next, we consider the role that natural inclusions may have played in the formation of the compositional groups in the Pinson NAA. Based on both chemical evidence (enrichment in rare-earth elements found mostly in clays) and direct observation with a binocular microscope, Mainfort et al. (1997:59) suggest that "Group 4 samples are... fine-paste variants of locally derived clays rather than representing nonlocal pottery imports to the Pinson area." This interpretation is testable with the petrographic data. Total volume of silt and sand grains, the vast majority of which are quartz, ought to be the most reliable parameter for evaluating the relative chemical impact of natural inclusions. Accordingly, we employ the sum of the volumetric percentages of silt and sand (both recorded in Tables 1–4) as the best available measure of the relative incidence of natural inclusions for each sample (Table 6).

Because the focus here is on natural inclusions, the four vessels with exotic grit tempers, the presumed exotic grog-tempered vessel (40-66), and the unique, biogenically tempered vessel (40-67) are excluded from this portion of our analysis. The six unassigned samples also are excluded because they do not constitute a group in their own right—they were lumped together solely because they could *not* be assigned to one of the other groups. This leaves 27 of the 39 samples for which we have both NAA and petrographic data that are characterized by predominantly "sand temper" (the two vessels with small amounts of bone and the four vessels with <10 percent grog *are* thus included, with their tempers not considered). These 27, then, form the primary basis for evaluating the proposition that textural differences account for at least some of the observed variation among the three local NAA compositional groups.

Table 6. Means and Standard Deviations for Volumes of Natural Inclusions (Silt + Sand) in Sand-Tempered Vessels by NAA Group.

NAA Groups	*Frequency*	*% Silt + Sand (Mean ± Std Dev)*
Group 1	2	16.5 ± .7
Group 3A	11	34.4 ± 4.9
Group 3B	10	25.1 ± 5.8
Group 4	4	20.8 ± .7
Totals	27	

As shown in Table 6 and in Figure 8, there is considerable between-group variability in the relative volumes of natural inclusions (mostly quartz), as expected if the amounts of inclusions contributed to the chemical differences between the groups. Group 1 stands out as having the lowest incidence of inclusions, especially silt, which may be at least partly why these two vessels were included with eight others in an outlier category (Mainfort et al. 1997:47).

Among the remaining three compositional groups (those considered local), there is considerable overlap and no marked clustering (Figure 8). Group 4 has

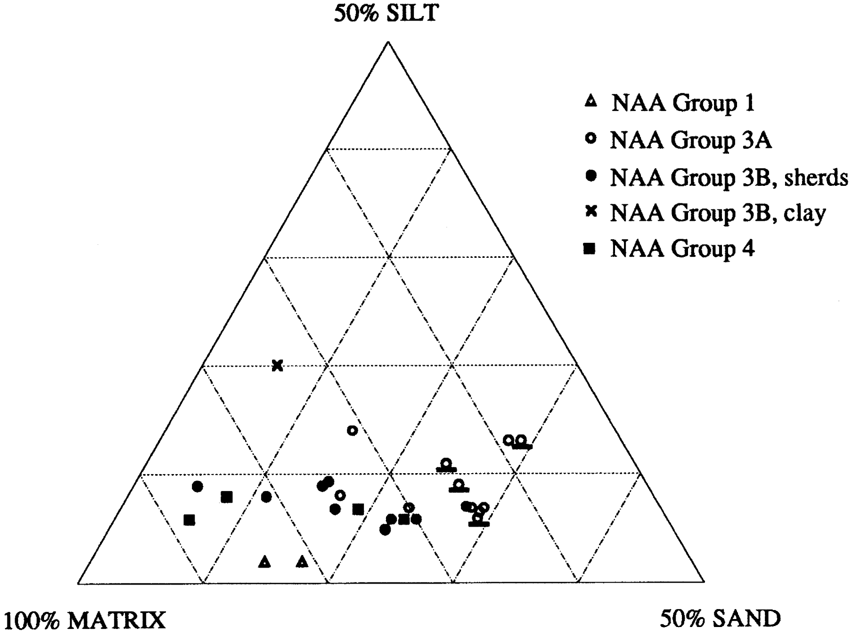

Figure 8. Ternary plot showing body values by NAA chemical group for the 26 predominantly sand-tempered sherds and one soil for which both petrographic and NAA compositional data are available. (The four complicated-stamped sherds, perhaps from a single vessel and all assigned to NAA Group 3A, are denoted by underlined circles.)

the lowest mean incidence of inclusions, consistent with its interpretation as a "fine-paste" class, in contrast to Groups 3A *and* 3B (Mainfort et al. 1997:59). On closer scrutiny, however, this interpretation is inconsistent with the data in Table 6, because Group 3B is actually more similar to Group 4 than it is to Group 3A. To aid in evaluating these data, t-tests comparing the combined silt and sand percentages for each group versus each of the other groups were performed, as follows:

Group 3A vs 3B	t=3.98, df=19, p=<.0005 >.00025 (highly significant)
Group 3A vs 4	t=4.02, df=13, p=<.001 >.0005 (highly significant)
Group 3B vs 4	t=1.13, df=12, p=>.19 (not significant)

These data suggest that differences in the amounts of silt and sand inclusions indeed contribute to NAA group differentiation, but they contradict the specific application of this premise employed in the NAA study. Contrary to the view expressed by Mainfort et al. (1997:59) that Group 4 differs from the two members of Group 3 on textural grounds, the petrographic data show that greater textural differences exist *within* chemical Group 3 than exist between one of the members of Group 3 (3B) and chemical Group 4.

Thus, the distributions of inclusions, whether exotic or local (i.e., quartz), follow no interpretable patterns within or between the compositional groups defined by NAA. On the one hand, several vessels with demonstrably exotic tempers were assigned to "local" chemical groups, while, on the other, quartz grains in the silt and sand size ranges show extensive and overlapping variability in their distribution among the "local" chemical groups. In light of these findings, it is difficult to make a case for inclusions *of any kind* having played a significant role in the formation of the chemical groups. Stated another way, the NAA compositional groups are so variable in the amount, size, and character of inclusions that no discernible patterns are evident that distinguish one group from the other.

A visual image of the enormous diversity of inclusions present within these NAA groups can be gained by comparing Figures 3 and 5, which show three vessels assigned to Group 3B, and by comparing the four vessels shown in Figure 4, all of which are assigned to compositional Group 3A (all of these figures are the same scale). That vessels as diverse as these share common chemical signatures indicates that the chemical derivation of the compositional groups is so complex and multifaceted that the role of inclusions is virtually impossible to isolate, thus comprehend, as an independent variable.

The Role of Diagenesis

One of the great strengths of NAA is its capacity to identify accurately a wide range of elements present, even in trace amounts, in almost any material. Determining the area of production of ceramics ultimately depends on matching chemical compositions of artifacts with places in the world where those same chemical signatures are found in naturally occurring raw materials. Ceramic source determination, however, is an extremely complex matter because of two important factors: (1) as humanly fabricated mixtures—minimally of clays, tempers, and water—ceramics rarely chemically match any naturally occurring substances (as, for example, can be done for native copper or obsidian artifacts), and (2) as highly porous materials, they are acutely susceptible to postdepositional alteration (diagenesis) once they enter the archaeological record.

While the importance of inclusions as contributors to the chemical signature of ceramic samples has been considered by NAA researchers, the role of diagenesis has so far received much less attention. Ceramics in archaeological contexts invariably are in contact not only with soils but also with water, "this major component of soil" that contains dissolved salts and makes up what is referred to as the "soil solution" (Buckman and Brady 1969:13). As a porous material residing in archaeological context, ceramics must be deemed highly susceptible to chemical alteration through interaction with soil solutions whose chemical content is a reflection primarily of the local depositional environment (Carr 1982:159–160). Depending on a myriad of factors—original chemical composition of the ceramics, mineralogical makeup of the soils, annual rainfall, drainage, time in the ground (over 1,500 years in the case of the Pinson Mounds ceramics)—the nature and extent of diagenesis will be variable, but, we suspect, rarely nonexistent. Although the precise impact of diagenesis on the Pinson ceramics cannot be determined, it is especially noteworthy that fully 30 percent of the elements assayed in the Pinson NAA study (seven of 23) are known to be mobile in soil solutions: barium, calcium, cesium, iron, manganese, potassium, and sodium (Arnold et al. 1991:71; Bishop and Neff 1989:65; Mainfort et al. 1997:47; 56–57). In sum, pottery is a prime candidate for significant diagenetic alteration after it enters the archaeological record, but NAA, which is capable of detecting the elements involved, will record them as if they were among the original constituents of the ceramic sample, even though enrichment or depletion is likely to have occurred.

The effects of diagenesis are particularly critical when the related issues of ceramic production and exchange are considered. The chemical signature of a hypothetical vessel made in Area A and traded to Area B can be expected to become less A-like and more B-like the longer it resides in the ground at B. Depending on the initial chemical differences between A and B, it seems to us entirely reasonable to infer that, given enough time, an imported vessel from Area A would either (1) acquire a chemical signature that would lead to its classification as *neither* A nor B, that is, as an "outlier," or (2) become sufficiently B-like to be classified as "local" during the statistical analysis.

Conclusions

This study compares and critically evaluates the differential results of petrography and NAA when applied to a common data set of sherds and soil samples from the Pinson Mounds region of west Tennessee. Although there is a disparity in the total number of samples analyzed using the two methods (164 by NAA, 52 by petrography), the 39 specimens to which *both* techniques have been applied provide a uniquely large sample of jointly analyzed sherds and soil samples with which to compare the findings of the two approaches directly. We undertook this research in order to assess the differential effectiveness of each method to address issues of ceramic production and exchange in prehistory. Unlike prior studies that employed petrography primarily in a supporting role to NAA, this study treats the two as independent approaches to the compositional analysis of a common sample of prehistoric ceramics.

In comparing the results of the two approaches, we have employed the enabling supposition that the thin-section sample is representative of both the larger NAA sample and its subgroups (see Table 5). We regard this supposition as reasonable, but since it is currently untested, the conclusions of the current study should be viewed with appropriate caution.

Interestingly, the two analyses resulted in distinctly contradictory interpretations. The NAA data were interpreted as reflecting only local ceramic production, even including several stylistically anomalous vessels. In contrast, we believe the petrographic evidence suggests that a significant minority of the sampled vessels were imported into the Pinson Mounds locality. Moreover, in addition to determining that fully one-quarter—nine of 35—of the coanalyzed vessels probably were imported, petrographic analysis identified as local products at least five vessels that the statistical analyses of the NAA data had excluded from the local groups, relegating them either to the "outlier" (the two Group 1 vessels) or "unassigned" (Vessels 40-64, 40-91, and 40-93) categories. These appear to be mutually exclusive conclusions that have profound implications for how the two approaches can and should be employed in making inferences about past human behavior from the compositional analysis of archaeological ceramics.

Since we had independent qualitative and quantitative data on the inclusions present in 39 vessels that had been analyzed by NAA, we attempted to assess the integrity of the NAA-derived compositional groups in terms of inclusions. A number of findings here are inconsistent with the expectation that inclusions should play an interpretable role in shaping NAA compositional groups. For example, despite the presence of what we recognize as definitely exotic tempers in at least five vessels (40-61, 40-65, 40-66, 40-70, and 40-81), four were assigned to local NAA groups. In a similar manner, quartz inclusions among the predominantly "sand-tempered" vessels did not show the intergroup differences expected on the basis of the chemically defined groups. Instead, members of Group 3B possess a texture closer to Group 4 than to Group 3A. Nonetheless, the petrographic analysis did reveal significant textural differences between some of the groups—notably Groups 3A and 4 and Groups 3A and 3B—suggesting that texture does play a significant, if difficult to interpret, role in the formation of NAA compositional groups.

Before the current study was completed, we were inclined to accept NAA groups or clusters more or less at face value as reflecting reliable chemical characterizations of the ceramics produced in specific regions. There is now reason to believe, we feel, that NAA-defined ceramic compositional groups (e.g., Groups

3A, 3B, and 4 in the Pinson analysis) are far more complex and heterogeneous than is generally realized. Tangible evidence for this assertion can be seen in Figures 3, 4, and 5, which clearly display the enormous qualitative and quantitative diversity of inclusions present *within* two of the chemical groups—3A (Figure 6) and 3B (Figures 3 and 4)—of the Pinson NAA study. This much demonstrable intragroup physical diversity is inconsistent with the chemical homogeneity that originally defined these groupings, thus raising serious questions about their integrity.

Besides documenting enormous and surprising physical heterogeneity of the NAA compositional groups defined in the Pinson Mounds study, our findings further disagree with the NAA analysis in the allocation of several specific vessels to local as opposed to "outlier" or "unassigned" (i.e., possibly nonlocal) status. In particular, the petrographic evidence suggests that at least two "outlier" (40-88 and 40-89) and three "unassigned" vessels (40-64, 40-91, and 40-93; Table l) are local products, while no fewer than five vessels that were assigned local status by NAA (40-61, 40-65, 40-66, 40-70, and 40-81) are, on the basis of substantial petrographic evidence, almost certainly of exotic origin.

As a result of these findings, it appears to us that the chemical signatures produced by NAA, while perhaps valid as broad statistical generalizations on a regional scale, are far too noisy to serve as reliable sorting criteria for evaluating the local versus nonlocal status of individual vessels. We suggest that these statistical statements (i.e., NAA-produced elemental inventories) have limited predictive power with respect to individual vessels for at least two reasons: (1) the elements that comprise them derive from so many independent sources simultaneously—especially clays, natural inclusions, tempers, water, and diagenesis—that equifinality must be viewed as a highly probable trajectory by which vessels of different compositions or sources may become joined within a single chemical group; and (2) the multivariate statistical procedures employed to define the chemical groups have the power to create as well as to discover patterning within the complex array of numbers generated by the NA analysis of large samples of ceramic vessels.

We suggest that more serious consideration be given to the possibility that NAA compositional characterizations of prehistoric ceramics are far more complex and imperfect statistical generalizations than is generally allowed because the chances are high that they are as much byproducts of the laboratory and statistical procedures involved as direct reflections of a past cultural world. So long as NAA continues to process *bulk* samples of sherds, we believe that the resultant chemical signatures, based as they are on a host of uncontrollable variables, too often will lack the cultural integrity generally attached to them. It is important to note that the sourcing of prehistoric ceramic artifacts is not at all analogous to sourcing artifacts made of materials like native copper or obsidian, whose chemical compositions can be reasonably expected to match natural outcrops, since the kinds of chemical alterations that accompany ceramic production and postdepositional alteration are not associated with such materials. The primary issue raised in this article is not the veracity of the numbers generated by

NAA, but how reliable inferences about past human behavior can be ferreted out of such complex arrays.

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